5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Ethylbenzene is an aromatic hydrocarbon naturally present in crude petroleum. It is widely distributed in the environment because of human activities such as the use of fuels and solvents (which account for the bulk of emissions) and through chemical manufacturing and production activities. Because of its volatile nature, partitioning into the atmosphere from various environmental media is an important environmental fate process. Exposure to this chemical is thus most likely to occur by inhalation. However, it is also present in trace amounts in some water supplies. Thus, ingestion also may be an important exposure pathway in some cases. Exposures from contaminated water may also occur via inhalation and dermal absorption during showering and other household activities (Beavers et al. 1996).

Physical, chemical, and biological processes can remove ethylbenzene from the medium of concern and reduce human exposures. In the atmosphere, ethylbenzene, which exists predominantly in the vapor phase, is removed by partitioning into rainwater or by chemical transformations caused by the sun's energy (photooxidation) via reaction with hydroxyl radicals, which structurally alter the molecule. Photolytic transformations may also take place in surface water in the presence of naturally occurring hurnic materials (sensitized photolysis). Biologically induced transformations take place largely in soil and surface water in the presence of oxygen; however, anaerobic degradation can also occur in soil, sediment, and groundwater. Although chemical transformations can result in reduced exposures to ethylbenzene in the atmosphere, one toxic by-product of ethylbenzene photodegradation, peroxyacetylnitrate (PAN) may be of concern. Ethylbenzene, as well as a variety of other hydrocarbons, has been implicated in the atmospheric formation of PAN in smog (Yanagihara et al. 1977).

The kinetics of partitioning and/or transformation processes are site specific and depend upon many external factors. For example, the extent of biodegradation observed in an environmental medium depends upon the type and population of microorganisms present, the concentration of ethylbenzene, the presence of other compounds that may act as a substrate, and the presence or absence of oxygen. Biodegradation in soil will also compete with migration processes such as volatilization and infiltration to groundwater. Because ethylbenzene migration is only moderately retarded by adsorption onto soil, rapid transport of the

compound to an anaerobic environment (groundwater) before biotransformation in soil is possible and may allow ethylbenzene to persist in an aquifer.

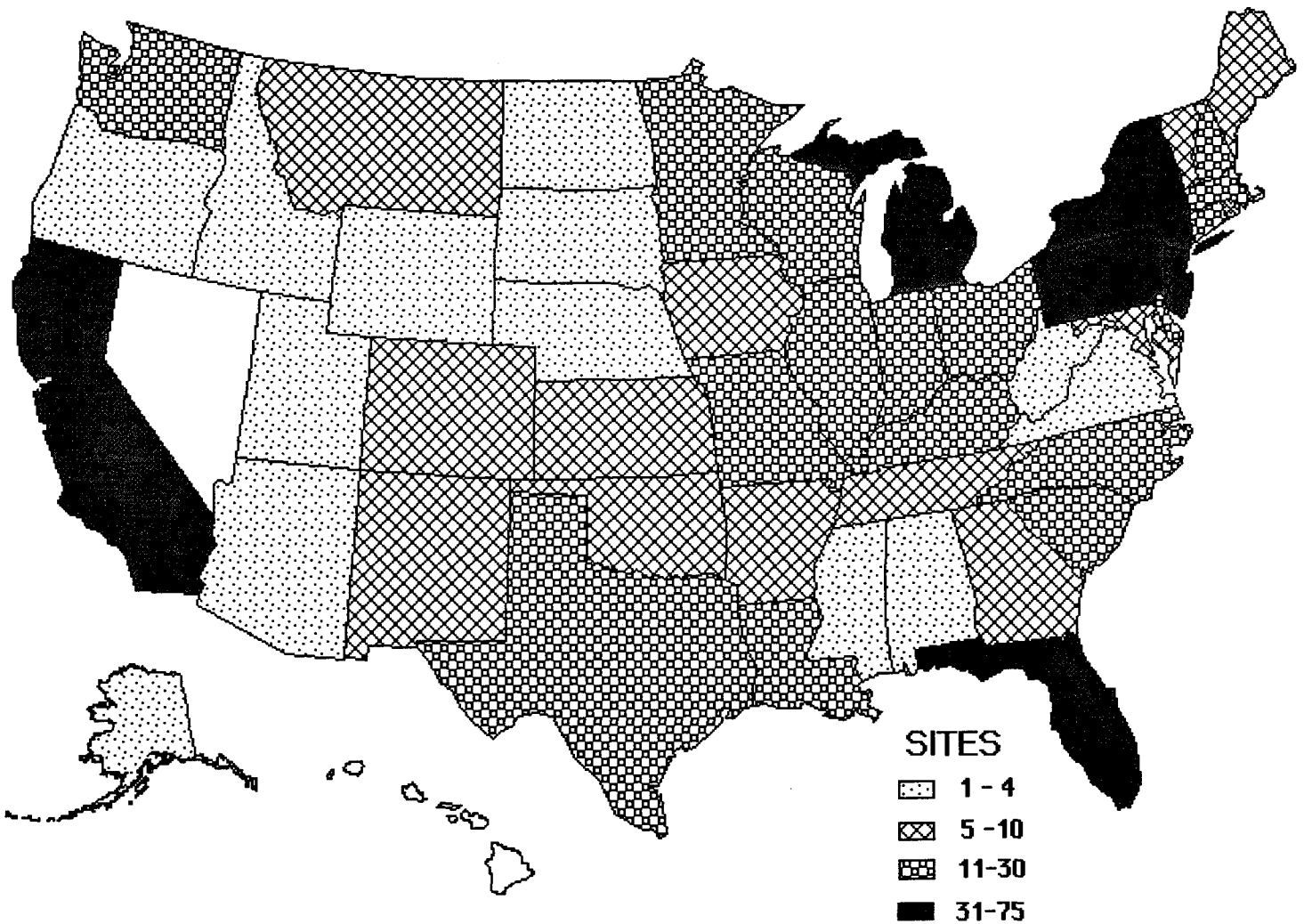
Although information is limited on dietary exposures, ethylbenzene does not appear to significantly bioaccumulate in aquatic or terrestrial food chains, and human exposure through this route is not likely to be of concern.

Exposure of the general population to ethylbenzene is possible through contact with gasoline, automobile emissions, solvents, pesticides, printing ink, varnishes, coatings, and paints. Cigarette smoke also has been identified as a source of exposure to this chemical. Ethylbenzene is widely present at low concentrations in rural, suburban, and urban atmospheres with the highest concentrations generally detected in areas of gasoline stations, tunnels, highways, and parking lots. Ethylbenzene is also typically present in indoor air at low concentrations (median = 1 ppb). Occupational exposures are expected within the petroleum industry; within industries using solvents, paints, and coatings; and during the manufacture and handling of ethylbenzene and styrene (which is manufactured from ethylbenzene).

Several groups within the general population may have potentially higher exposures to ethylbenzene by inhalation or by consumption of or dermal contact with contaminated drinking water or soil. These groups include individuals living near manufacturing and processing facilities, petroleum refineries, and hazardous waste disposal sites. Exposures associated with the consumption of contaminated drinking water as well as with inhalation and dermal exposure during showering and bathing in contaminated water would be expected for individuals that derive their primary drinking water supply from residential wells downgradient of uncontrolled landfills, hazardous waste sites, and leaking underground storage tanks that are contaminated with ethylbenzene. Individuals living near these sites may also be exposed via dermal contact with, or ingestion of soil contaminated with ethylbenzene.

Ethylbenzene has been identified in at least 731 of the 1,467 current or former EPA NPL hazardous wastes sites (HazDat 1998). However, the number of sites evaluated for ethylbenzene is not known. The frequency of these sites within the United States can be seen in Figure 5-1. Of these sites, 718 are located in the United States and 2 are located in the Commonwealth of Puerto Rico (not shown).

Figure 5-1. Frequency of NPL Sites with Ethylbenzene Contamination



Derived from HazDat 1998

5.2 RELEASES TO THE ENVIRONMENT

According to the Toxics Release Inventory (TRI), in 1996, a total of 27538,543 pounds (12,491,273 kg) of ethylbenzene was released to the environment from 95 1 large processing facilities (TR196 1998). Table 5-l lists amounts released from these facilities. Of the total release, an estimated 76,352 pounds (34,633 kg) were released by manufacturing and processing facilities to publicly owned treatment works (POTWs) and an estimated 17,733,077 pounds (8,043,588 kg) were transferred offsite (TR196 1998). The TRI data should be used with caution because only certain types of facilities are required to report (EPA 1995d). Therefore, this is not an exhaustive list. Facilities are required to report data to TRI if they have 10 or more full-time employees, if the facility is classified under Standard Industrial Classification (SIC) codes 20 through 39, if the facility manufactures or processes more than 25,000 pounds of the chemical, or otherwise uses more than 10,000 pounds of the chemical in the calendar year (EPA 1995d).
Ethylbenzene has been identified in a variety of environmental media (air, soil gas, surface water, groundwater, leachate, soil, and sediment) collected at 731 of the 1,467 NPL hazardous waste sites (HazDat 1998). The frequency of these sites within the United States can be seen in Figure 5-l.

5.2.1 Air

The majority of ethylbenzene releases to the environment occur to the atmosphere. Because of its frequent use, and production in manufacturing operations, ethylbenzene is an important industrial chemical. In 1994, ethylbenzene was ranked 19th among the top 50 chemicals produced in the United States, with total production estimated to be almost 12 billion pounds (C&EN 1995a). Its release can occur during manufacturing, processing, and handling. In 1978, emissions of ethylbenzene in the United States from catalytic reformate production alone were estimated at over 2 million pounds (Fishbein 1985). Fuels and solvents, however, are considered to account for the bulk of emissions (Fishbein 1985). Gasoline contains approximately 2% (by weight) ethylbenzene, which is added as an anti-knocking agent (Mayrsohn et al. 1978 as cited in NAS 1980). Ethylbenzene has been measured from tail pipe emissions of gasolinepowered vehicles at a weighted average rate of 12 mg/km (considering both catalyst and noncatalyst equipped cars) (Hampton et al. 1983). Exposures to ethylbenzene can also occur while individuals are traveling in the passenger compartment of automobiles, and the chemical has been found at much higher concentrations during automobile engine malfunctions (Lawryk and Weisel 1996; Lawryk et al. 1995).

Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Ethylbenzene

		Total of reported amounts released in pounds per year [a]						
STATE [b]	NUMBER OF FACILITIES	AIR [c]	WATER	LAND	UNDERGROUND INJECTION	POTW TRANSFER	OFF-SITE WASTE TRANSFER	TOTAL ENVIRONMENT [d]
AK	2	20,935	1	400	0	0	9	21,345
AL	26	254,092	1,000	0	0	250	373,496	628,838
AR	18	230,878	89	250	0	0	177,062	408,279
AZ	2	1,406	0	0	0	0	10,550	11,956
CA	53	61,082	22	280	250	7,314	420,563	489,511
CO	4	3,449	0	0	0	0	510	3,959
CT	8	8,658	333	0	0	1	121,438	130,430
DE	3	29,850	0	0	0	0	71,991	101,841
FL	12	147,452	0	0	0	307	304,669	452,428
GA	18	208,611	0	0	0	20	447,509	656,140
HI	2	4,308	0	255	0	0	395	4,958
IA	16	219,330	0	0	0	0	150,854	370,184
IL	74	292,442	399	898	0	5,737	1,830,466	2,129,942
IN	52	450,161	307	292	0	10	369,197	819,967
KS	17	169,415	35	0	0	5	144,118	313,573
KY	20	665,455	109	1,721	0	420	583,112	1,250,817
LA	41	306,031	621	530	2,099	76	217,752	527,109
MA	5	2,641	0	0	0	0	21,938	24,579
MD	9	112,806	6	0	0	77	124,454	237,343
ME	2	2,916	0	0	0	0	15,841	18,757
MI	54	1,215,104	0	0	0	2,947	4,033,468	5,251,519
MN	15	188,441	27	0	0	5	169,773	358,246
MO	30	897,437	0	0	0	757	593,269	1,491,463
MS	19	393,271	46	12	0	5	217,225	610,559
MT	4	21,450	9	5	0	5	1,078	22,547
NC	18	97,516	0	0	0	2,600	122,470	222,586
ND	2	14,674	0	0	0	0	528	15,202
NE	5	74,648	5	0	0	0	3,936	78,589
NH	2	41,882	0	0	0	0	2,050	43,932
NJ	28	102,897	153	0	0	387	680,200	783,637
NM	5	46,537	0	510	0	250	1,318	48,615

Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Ethylbenzene (continued)

		Total of reported amounts released in pounds per year [a]						
STATE [b]	NUMBER OF FACILITIES	AIR [c]	WATER	LAND	UNDERGROUND INJECTION	POTW TRANSFER	OFF-SITE WASTE TRANSFER	TOTAL ENVIRONMENT [d]
NV	2	131	0	0	0	0	0	131
NY	15	94,489	65	0	0	5	309,826	404,385
OH	75	675,661	36	2,006	40	2,143	2,379,358	3,059,244
OK	13	130,924	48	36	0	209	68,517	199,734
OR	6	12,640	0	0	0	0	7,166	19,806
PA	49	248,275	264	2	0	10,526	799,691	1,058,758
PR	6	35,888	1,108	0	0	0	1,172,432	1,209,428
RI	2	13,460	0	0	0	0	3,100	16,560
SC	8	46,321	0	0	0	250	156,198	202,769
SD	4	39,339	0	0	0	0	18,904	58,243
TN	17	163,094	6	0	0	1,303	128,583	292,986
TX	107	757,335	641	53,662	333,538	38,958	1,019,155	2,203,289
UT	8	8,893	250	75	0	1,327	516	11,061
VA	14	334,907	721	0	0	39	31,098	366,765
VI	1	36,179	1	0	0	0	3,192	39,372
VT	1	905	0	0	0	250	250	1,405
WA	14	120,021	13	13	0	0	7,804	127,851
WI	22	160,632	0	0	0	169	338,806	499,607
WV	15	121,992	500	0	0	0	77,146	199,638
WY	6	37,422	260	877	5	0	96	38,660

Source: TRI96 1998

[a] Data in TRI are maximum amounts released by each facility

[b] Post office state abbreviations used

[c] The sum of fugitive and stack releases are included in releases to air by a given facility

[d] The sum of all releases of the chemical to air, land, and water, and underground injection wells; and transfers off-site by a given facility

POTW = publicly owned treatment works

Emissions from gasoline-powered vehicles were found to be somewhat higher than from diesel trucks (Hampton et al. 1983). Similarly, ethylbenzene has been measured in jet fuel emissions (Katzman and Libby 1975) and has been reported in waste incinerator stack emissions (Jay and Stieglitz 1995; Junk and Ford 1980). Most recently, ethylbenzene has been shown to be released into the atmosphere from volatile organic compound (VOC)-laden waste water in municipal sewer systems (Quigley and Corsi 1995).

Emissions of ethylbenzene can arise from transport of hot asphalt from a manufacturing plant to a paving site and from subsequent road paving operations. Kitto et al. (1997) measured the emissions of volatile organic compounds from Type I and Type II hot asphalts. At 150°C, the concentration of the ethylbenzene emissions from Type I asphalt was 800 μg/m^3; at 200°C, the concentration was 2,200 μg/m^3, an increase by a factor of 2.8. At 150°C, the concentration of the ethylbenzene emissions from Type II asphalt was 7000 μg/m^3; at 200°C, the concentration was 21,000 μg/m^3, an increase by a factor of 3.

Mukund et al. (1996) conducted chemical mass balance source apportionment modeling on a data set of 142 3-hour integrated air samples collected at six different sites in three separate campaigns during the summer of 1989 in Columbus, OH. The contributions (± standard error) from the sources considered, expressed as percentage of measured average concentration, were 55±11 from vehicle exhaust, 0.7&2 from gasoline vapor, 0±3 from natural gas, 20+4 from industrial solvents, and 0±1 from the drycleaning/ degreasing/wastewater composite source. These five sources contributed 76±12% of the measured average concentration of 1.1 μg/m^3.

Ethylbenzene releases to the air especially in indoor environments can occur with the use of consumer products such as pesticides, liquid process photocopiers and plotters, solvents, carpet glue, paints, varnishes, automotive products, adhesives, and fabric and leather treatments (Hodgson et al. 1991; Lillo et al. 1990; NAS 1980; Otson et al. 1994; Sack et al. 1992; Wallace et al. 1987b). Ethylbenzene (in addition to other aromatic hydrocarbons, such as benzene, styrene, and xylenes) has also been measured in cigarette smoke (Barrefors and Petersson 1993; Wallace et al. 1986, 1987c). A recent study of indoor air in a home using gasoline-contaminated drinking water found that exposures to ethylbenzene could occur via inhalation during showering and other household activities (Beavers et al. 1996). Ethylbenzene concentrations in shower air were often one to two orders of magnitude higher than non-shower air.

According to the TRI, in 1996, the estimated releases of ethylbenzene of 9,324,283 pounds (4,229,424 kg) to air from 951 large processing facilities accounted for about 33.9% of total environmental releases (TR196 1998). Table 5-1 lists amounts released from these facilities. The TRI data should be used with caution, however, since only certain types of facilities are required to report (EPA 1995d). Therefore, this is not an exhaustive list.

Ethylbenzene has been identified in air and soil gas samples collected at 87 and 44 of the 731 NPL hazardous waste sites respectively, where it was detected in some environmental media (HazDat 1998).

5.2.2 Water

Releases to water can occur as a result of industrial discharges (Snider and Manning 1982), fuel spillage (Gschwend et al. 1982; Tester and Harker 198l), leaking petroleum pipelines or underground storage tanks (Cotruvo 1985), landfill leachate (Barker 1987; Beavers et al. 1996; Chen and Zoltek 1995; Hallbourg et al. 1992), and the inappropriate disposal of wastes containing ethylbenzene (Eiceman et al. 1986). Ocean releases occur as a result of offshore oil production, hydrocarbon venting, oil field brines, and tanker oil spills (Sauer et al. 1978). Sauer and Tyler (1995) recently reported that ethylbenzene was one of the most commonly detected VOCs in motor vehicle waste fluids released from routine vehicle maintenance shops entering catch basins and septic tanks in Wisconsin. Ethylbenzene was detected at a mean concentration of 11 ppb (range 3-98 ppb) in catch basin waste water, 1.5 ppb (range 7-23 ppb) in septic tank effluent, and 8 ppb (range 9-53 ppb) in septic tank sludge.

According to the TRI, in 1996, the estimated releases of ethylbenzene of 7,075 pounds (3,209 kg) to water from 95 1 large processing facilities accounted for less than 0.1% of total environmental releases (TR196 1998). However, 76,352 pounds (34,633 kg) were released indirectly to POTWs and some of this volume may have been released to surface water. Table 5-l lists amounts released from these facilities. The TRI data should be used with caution, however, since only certain types of facilities are required to report (EPA 1995d). This is not an exhaustive list.

Ethylbenzene has been identified in surface water, groundwater, and leachate samples collected at 115, 488, and 92 of the 731 NPL hazardous waste sites respectively, where it was detected in some environmental media (HazDat 1998).

5.2.3 Soil

Ethylbenzene can be released to soils through the spilling of gasoline and other fuels (Sauer and Tyler 1995; Tester and Harker 1981); through the disposal of solvents and household products such as paint, cleaning and degreasing solvents, varnishes, and pesticides; through emissions from leaking underground storage tanks (Cotruvo 1985), and leaching from landfill sites (Barker 1987).

According to the TRI, in 1996, the estimated releases of ethylbenzene of 61,824 pounds (28,043 kg) to soil from 951 large processing facilities accounted for about 0.2% of total environmental releases (TR196 1998). In addition, an estimated 335,932 pounds (152,376 kg) or 1.2% of total environmental releases were released via underground injection. Table 5-1 lists amounts released from these facilities. The TRI data should be used with caution, however, since only certain types of facilities are required to report (EPA 1995d). This is not an exhaustive list.

Ethylbenzene has been identified in soil and sediment samples collected at 379 and 132 of the 73 1 NPL hazardous waste sites respectively, where it was detected in some environmental media (HazDat 1998).

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

The moderately high vapor pressure of ethylbenzene (Table 3-2) suggests a moderate to strong tendency for ethylbenzene to partition into the atmosphere where it will exist predominantly in the vapor phase (Eisenreich et al. 198 1; Mackay 1979; Masten et al. 1994). Depending upon site-specific conditions, releases to surface soil can result in substantial losses to the atmosphere in addition to subsurface infiltration. Since it has a moderately high vapor pressure, ethylbenzene will evaporate fairly rapidly from dry soil. Vapor phase transport will occur from subsurface releases (i.e., from leaking underground storage tanks) and during migration through unsaturated soil pore spaces (Rhue et al. 1988). This vapor phase migration is measured using soil gas sampling methods. Atmospheric reaction with hydroxyl radicals can limit the atmospheric ethylbenzene transport (Dewulf and van Langenhove 1997).

The high Henry's law constant (Table 3-2) which measures partitioning between water and air, indicates that a significant proportion of ethylbenzene will partition from water into air (Mackay 1979; Masten et al. 1994). Ethylbenzene dissolved in surface water, soil pore water, or groundwater will thus migrate into an available atmospheric compartment until its saturated vapor concentration is reached. Based on its K_{oc} value (Table 3-2) and using the classification scheme of Swann et al. (1983), ethylbenzene is classified as having moderate mobility in soils. Sorption and retardation by soil organic carbon content will occur to a moderate extent, but sorption is not significant enough to completely prevent migration in most soils. Particularly in soils with low organic carbon content, ethylbenzene will tend to leach into groundwater. Mobility is also possible in aquifers that contain very little solid-phase organic matter, a condition common to sand and gravel aquifers (Ptacek et al. 1984). Sorption and desorption experiments performed by Dewulf et al. (1996) demonstrated that the sorption process of ethylbenzene on marine sediments is reversible and that the sorption is even lower than expected from the log K_{ow} data and the organic carbon content of the sediment. They concluded that the marine sediment compartment is not an important sink for the VOCs investigated when they are brought into the environment.

When ethylbenzene is part of a complex mixture of hydrocarbons associated with a petroleum spill or leak, the proportion of ethylbenzene that will bind to soil versus the amount that will migrate toward groundwater depends primarily on the type of soil, the particular petroleum product in which the ethylbenzene is dissolved, the size of the spill, and the amount of rainfall (Stokman 1987). For example, the solubility of ethylbenzene varies in accordance with the presence of other petroleum products (Ptacek et al. 1984). While the pure compound solubility of ethylbenzene in water is 180 mg/L, its solubility in water equilibrated with JP-jet fuel is 10.6 mg/L (Burris and MacIntyre 1984). Potter (1993) also reported that the equilibrium aqueous solubility of ethylbenzene was 2.4 mg/L with gasoline, 0.18 mg/L with diesel fuel, and 0.007 mg/L with #6 fuel oil equilibrated with groundwater. Both of these authors calculated the solubility concentrations of ethylbenzene in water equilibrated with various petroleum products. In addition, solvent spills of chemicals such as ethylbenzene may enhance the mobility of other organic chemicals, which do strongly adsorb to soil (Rao et al. 1985). No information was found concerning bioavailability of ethylbenzene from soil for human dermal or oral uptake.

Boyd et al. (1990) reported that corn residues absorbed a significantly greater amount of ethylbenzene as compared with surface soil. The authors suggested that the highly lipophilic plant cuticle appears to be the

sorptive component. Kango and Quinn (1989) also reported that humic acid adsorbed higher amounts of ethylbenzene and xylenes ranging from 40 to 77 times greater than soil.

Once in the atmosphere, ethylbenzene will be transported until it is removed by physical or chemical processes. Physical removal processes, which involve partitioning into clouds or rainwater, are relevant to ethylbenzene, which has been measured in Los Angeles rainwater (Kawamura and Kaplan 1983). The concentrations of several dissolved organic chemicals in rainwater and in the atmosphere during rainfall events were measured by Ligocki et al. (1985). The authors found that the concentration of ethylbenzene in rainwater was approximately equal to the inverse of the dimensionless Henry's law constant (Table 3-2) at atmospheric temperatures. This indicates that ethylbenzene is removed from the atmosphere through precipitation, but it can re-enter the atmospheric environment upon evaporation.

In comparison to chemicals such as polychlorinated biphenyls (PCBs), DDT, and other chlorinated pesticides, which are of great concern with respect to bioaccumulation, ethylbenzene does not significantly bioaccumulate in aquatic food chains. A bioconcentration factor (BCF) in fish of 37.5 based on a log K_{ow} of 3.15 has been estimated (EPA 1980). A 3% weighted average lipid content in fish and shellfish was assumed by EPA in the calculation. The calculated BCF is a theoretical value based on known constants, and is a conservative estimate of the bioconcentration of this chemical in fish. A calculated BCF of 167 was also estimated for fathead minnows *(Pimephales promelas)* (ASTER 1995). In a shellfish study, the ethylbenzene concentration in clam tissue was 5 times higher than that measured in water after an 8-day continuous-flow exposure to the water-soluble fraction of Cook Inlet crude oil (Nunes and Benville 1979).

Ethylbenzene has also been found to partition into human tissues, primarily as a result of inhalation exposures (see Section 5.5). Ethylbenzene has been detected in human adipose tissue (Section 2.3.2. l), blood (Sections 2.2.1 and 2.3.1), and in breast milk (Sections 2.6 and 2.7.1). No information was located concerning the bioavailability of ethylbenzene from contaminated soil or sediment either with respect to dermal exposure or oral intake via consumption of soil particles from unwashed hands.

5.3.2 Transformation and Degradation

5.3.2.1 Air

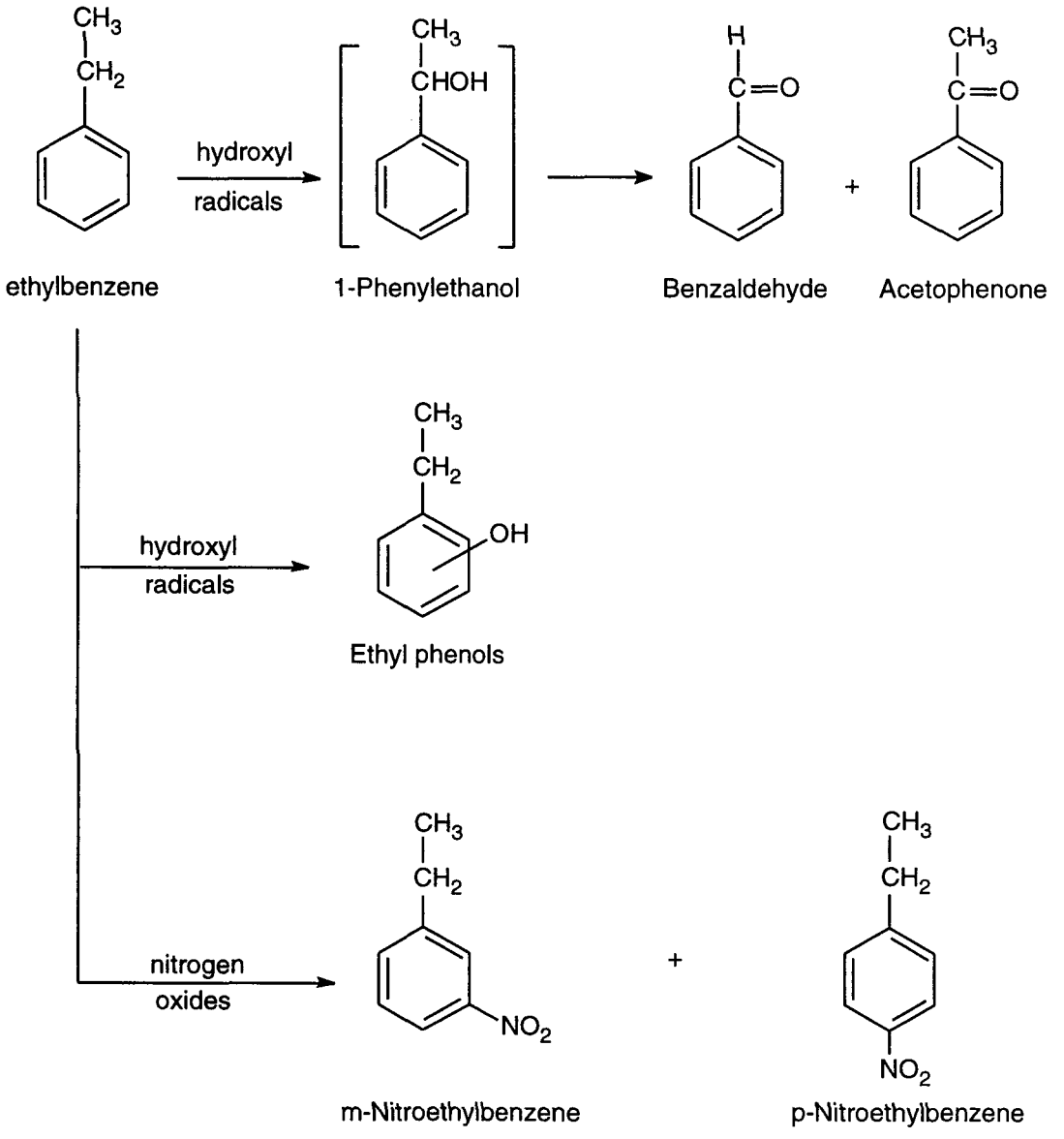
Ethylbenzene undergoes atmospheric transformations through reaction with photolytically generated hydroxyl radicals (Atkinson et al. 1978; Ohta and Ohyama 1985; Ravishankara et al. 1978), NO_3 radicals (Atkinson et al. 1987), and atomic oxygen (Grovenstein and Mosher 1970; Herron and Huie 1973). Gas phase reactions with ozone and structurally similar molecules such as toluene have been observed (Atkinson and Carter 1984). Reactions with hydroxyl radicals appear to be of most importance, and a chemical lifetime of 35 daylight hours for ethylbenzene has been estimated (Atkinson et al. 1978). An atmospheric half-life of 2.7 days (65 hours) was estimated using the Atmospheric Oxidation Program (SRC 1995). Degradation appears to be somewhat faster (half-life of 5.5 hours) in summer than in winter (halflife 24 hours) (Ravishankara et al. 1978; Singh et al. 198l), and faster under photochemical smog conditions (Dilling et al. 1976). Oxidation by-products from the reaction with hydroxyl radicals and nitrogen oxides include ethylphenols, benzaldehyde, acetophenone, and *m*- and *p*-nitroethylbenzene (Hoshino et al. 1978). The major degradation pathways for ethylbenzene in the atmosphere are summarized in Figure 5-2.

Experiments conducted with various hydrocarbons on the formation of photochemical aerosols or the haze associated with smog revealed that aromatics such as ethylbenzene produced only low yields of aerosol when compared with more reactive compounds such as alkenes (O'Brien et al. 1975). The formation of peroxyacetylnitrate (PAN) is related to the photoreactivity of the reacting hydrocarbon. The photoreactivity of ethylbenzene is intermediate relative to other atmospheric hydrocarbons, and it is less reactive than gasoline, toluene, and alkenes such as propene (Yanagihara et al. 1977).

5.3.2.2 Water

In surface water, transformations of ethylbenzene may occur through two primary processesphotooxidation and biodegradation. Although ethylbenzene does not directly absorb light wavelengths that reach the troposphere, it is capable of undergoing photooxidation in water through an indirect reaction with other light-absorbing molecules, a process known as sensitized photolysis. The compounds 1-methylphenyl ketone (acetophenone), 1-phenylethanol, and benzaldehyde were identified from the laboratory

Figure 5-2. Major Degradation Pathways for Ethylbenzene in the Atmosphere



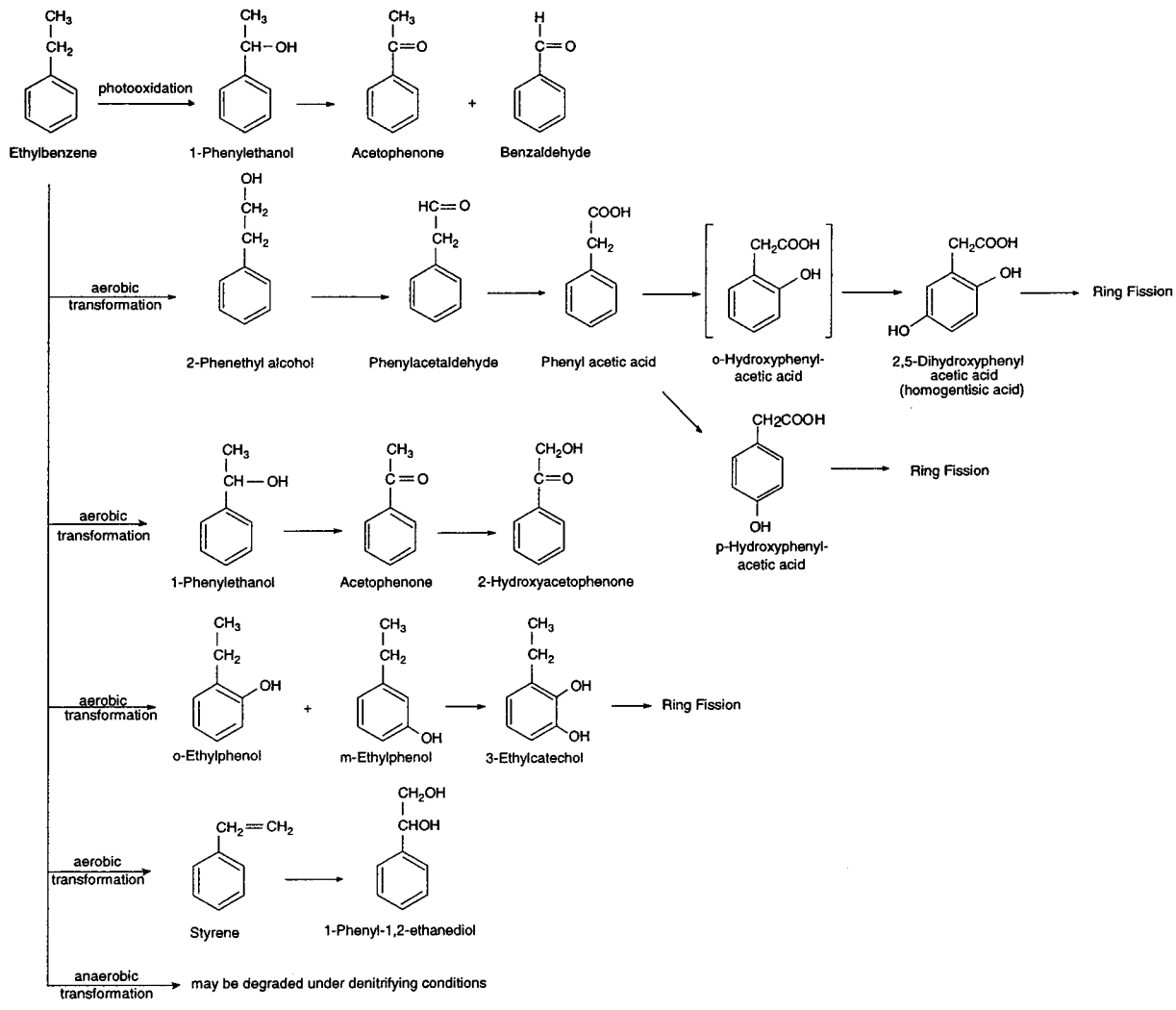
Source: Hoshino et al. 1978

photooxidation of ethylbenzene in both distilled water and seawater with acetophenone used as a sensitizer (Ehrhardt and Petrick 1984). In the environment, similar degradation is expected to occur in the presence of ubiquitous, naturally occurring humic material sensitizers. The major degradation pathways for ethylbenzene in water are summarized in Figure 5-3.

Biodegradation in aerobic surface water will compete with sensitized photolysis and transport processes such as volatilization. Volatilization and biodegradation of ethylbenzene in seawater have been observed by Gschwend et al. (1982), Masten et al. (1994), and Wakeham et al. (1983). Migration from surface water to subsurface soil with low amounts of oxygen or to aquifers with lower microbial populations, however, will limit the rate of transformation. No significant disappearance of ethylbenzene during 11 weeks of incubation with bacteria under low oxygen (anoxic) conditions was observed by Bouwer and McCarty (1983). Slow degradation of ethylbenzene was reported in anaerobic aquifer materials known to support methanogenesis, although a long acclimation period or lag time was required (Wilson et al. 1986). Less than 1% of the initial concentration of ethylbenzene remained after 120 weeks, indicating that, given sufficient time, ethylbenzene will be essentially completely biodegraded.

Laboratory microcosm tests were conducted to determine optimum conditions for ethylbenzene biodegradation by aquifer microorganisms under denitrifying condition (Hutchins 199 1). Ethylbenzene was degraded to below 5 μg/L when present as a sole source substrate and stoichiometric calculations indicated that nitrate removal was sufficient to account for 70 to 80% of the compound being mineralized. Biodegradation did not occur without the presence of nitrate, and nitrate removal was minimal without the presence of the ethylbenzene over a 55-day incubation period. In a laboratory microcosm containing aquifer material and groundwater from the North Bay site in Ontario, Canada, no significant loss of ethylbenzene was observed compared to unamended controls over a period of 187 days. In another experiment conducted at the North Bay site that used in *situ* biodegradation columns, ethylbenzene was completely degraded in at least 1 of the 8 in situ columns in less than 100 days (Acton and Barker 1992). In all cases, the authors attributed the ethylbenzene attenuation to biodegradation by methanogenic and fermentative bacteria. In another study using a laboratory scale flow-through aquifer column system, low dissolved oxygen (<l mg/L) conditions were initiated with the nitrate-amended column influent in order to mimic contaminated groundwater Fonditions distal from a nutrient injection well (Anid et al. 1993). The authors reported that 40% of the ethylbenzene was removed after several months of operation. In a similar study, using batch incubations seeded with 4 different aquifer materials, ethylbenzene was not degraded within

Figure 5-3. Major Degradation Pathways for Ethylbenzene in Water, Sediment, and Soil



Sources: Ehrhardt and Petrick 1984; Van DerLinden and Thijsse 1965; Burback and Perry 1993; Lee and Gibson 1996

4 months in any of the denitrifying enrichments tested, even though nitrate reduction occurred. Burback and Perry (1993) reported than Mycobacterium vaccae can catabolize a number of major groundwater pollutants, including ethylbenzene. At a concentration of 100 ppm ethylbenzene was not measurably degraded; however, at 50 ppm, 80% of the added ethylbenzene was degraded. A product peak of 4-ethylphenol was detected as well as a small amount of I-phenylethanol.

The contrast between biodegradation rates in the presence or absence of oxygen was demonstrated by a biofilm reactor study designed to simulate an aquifer (Bouwer and McCarty 1984). Continuous-flow laboratory column studies under aerobic and methanogenic conditions were performed with mixed bacterial cultures on glass beads. In the aerobic biofilm column, 99% of the ethylbenzene initially present was degraded within a 20minute detention time, while under methanogenic (anaerobic) conditions, only 7% was degraded within a 2-day detention time.

5.3.2.3 Sediment and Soil

Biodegradation of ethylbenzene by aerobic soil microbes has been reported by various researchers. The common soil microorganism *Pseudomonas putidu* is able to utilize ethylbenzene as a sole source of carbon and energy (Fukuda et al. 1989; Gibson et al. 1973). In some instances, co-oxidation or co-metabolism was observed (i.e., ethylbenzene was degraded by *Nocurdiu* sp. in the presence of other compounds that are more readily metabolized by the microorganism) (Jamison et al. 1970; Van der Linden and Thijsse 1965). Yadav and Reddy (1993) reported that the white-rot fungus *Phanerochaete chrysosporium* efficiently degraded ethylbenzene as well as other benzene, toluene, ethylbenzene and xylenes (BTEX) compounds when these chemicals were added either individually or as a composite mixture. In addition, substantially greater degradation of all the BTEX compounds was observed in static rather than in shaken liquid cultures. Furthermore, degradation was greater at 25°C than at 37°C, but pH variations between 4.5 and 7 had little effect on the extent of the degradation. Chen and Taylor (1995) reported that 2 thermophilic bacterial strains, *Thermus uquuticus* and an unidentified *Thermus sp.* degraded ethylbenzene (in a mixture with other BTEX chemicals) by 18% after 45 days of incubation at 70°C and by 32% after 45 days of incubation at 60°C respectively. Zappi et al. (1996) reported that ethylbenzene degraded rapidly in a pilot scale bioslurry reactor under aerobic conditions. The initial concentration (0.35 mg/kg) was degraded by 94% in 2 days.

Biotic transformations by aerobic soil microbes involve oxidation of the ethyl side chain to form phenylacetic acid (Van Der Linden and Thijsse 1965) and 1-phenylethanol (Bestetti and Galli 1984 as cited in ECETOC 1986); ring hydroxylation to form 2,3-dihydroxy-1-ethylbenzene (Gibson et al. 1973), 2-hydroxyphenlacetic acid, 4-hydroxyphenylacetic acid, and 2,5- and 3,4-dihydroxyphenylacetic acid (Van der Linden and Thijsse 1965); and ultimate ring cleavage to form straight chain carboxylic acids such as fumaric and acetoacetic acids (Van der Linden and Thijsse 1965). The major degradation pathways for ethylbenzene are summarized in Figure 5-3.

Anaerobic degradation of ethylbenzene based on observations from studies conducted under anaerobic conditions in other media and as discussed above (Bouwer and McCarty 1983, 1984; Wilson et al. 1986), would be much slower than that observed under aerobic conditions. Ramanand et al. (1995) studied the biodegradation of several organic pollutants including ethylbenzene in soil columns under denitrifying conditions. These authors reported that one of the significant factors governing biodegradation is the availability of suitable electron acceptors. The biodegradation of ethylbenzene, toluene, and xylenes has been demonstrated in laboratory samples obtained from subsurface habitats or in pure cultures under dinitrifying conditions (Hutchins 1991; Hutchins et al. 1991). Ramanand et al. (1995) reported that soil column bacteria, after sufficient acclimation time, metabolized 100-500 μM of toluene and ethylbenzene in less than 6 days under denitrifying conditions. These compounds were successfully degraded under anoxic conditions by the addition of nitrate and by stimulating the indigenous soil denitrifying bacteria.

The kinetics of biodegradation appear to be site specific, and depend upon factors such as the type and population of microbes present, the environmental temperature, the concentration of ethylbenzene, the presence of other compounds that may act as a substrate, and the amount of oxygen and electron acceptors present. Biodegradation in soil will also compete with migration processes such as volatilization and infiltration to groundwater.

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to ethylbenzene depends in part on the reliability of supporting analytical data from environmental samples and biological specimens. In reviewing data on ethylbenzene levels monitored or estimated in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable. The

analytical methods available for monitoring ethylbenzene in various environmental media are detailed in Chapter 6.

5.4.1 Air

Ambient air levels of 'volatile organic compounds, including ethylbenzene, were monitored as a part of a multi-media study known as the Lower Rio Grande Valley Environmental Scoping Study. Monitoring was preformed at a "central" site and at a "border" site in the Brownsville, Texas, air shed in the spring and summer of 1993. The median ambient concentration of ethylbenzene at the central site was 0.8 $\mu g/m^3$ (n=22; range=0.2-1.7 $\mu g/m^3$) in the spring and 0.4 $\mu g/m^3$ (n=14; range=0.2- 1 .0 $\mu g/m^3$) in the summer. These concentrations are either lower or comparable to those found in previous EPA and other monitoring investigations (Ellenson et al. 1997). The median indoor concentration of ethylbenzene for nine Ria Grande Valley residences measured in the spring was 1.00 $\mu g/m^3$ compared to a median outdoor concentration of 0.70 $\mu g/m^3$; in the summer, the median indoor concentration of ethylbenzene for five residences was 1.40 $\mu g/m^3$ compared to a median outdoor concentration of 0.35 $\mu g/m^3$ (Mukerjee et al. 1997).

An update of the 1980 National Ambient Volatile Organic Compounds (VOC) database prepared for EPA summarized concentrations of ethylbenzene by site type (Shah and Heyerdahl 1988). Median values are reported because they are less biased by a few high or low concentrations and, thus, may better represent the data than would average values. The median indoor concentration of ethylbenzene detected at 95 locations was 1 ppb (mean 2.9 ppb), while personal air monitoring of 1,650 individuals found a median concentration of 1.3 ppb (mean 3.2 ppb).

Of particular interest is that personal air monitoring of indoor air found higher concentrations of ethylbenzene than those observed in outdoor air. This was also observed during the Total Exposure Assessment Methodology (TEAM) Study conducted by EPA between 1979 and 1985 in an effort to measure exposures to 20 VOCs in personal air, outdoor air, and drinking water. The major cause for the higher personal air concentrations was felt to be the presence of ethylbenzene sources in the home. In the TEAM study, tobacco smoke was reported to be a main source of exposure to volatile aromatic compounds such as ethyl-benzene (Wallace et al. 1987a, 1987c). Based on the results of a stepwise regression carried out on data collected during the fall in New Jersey from 352 participants, overnight geometric mean ethylbenzene exposures of persons living in homes with smokers were approximately 1.5 times the geometric mean

exposures of persons living in homes without smokers. The amount of ethylbenzene measured in mainstream smoke of a single cigarette containing 16 mg of tar and nicotine was 8 l..tg (Wallace et al. 1987c). More recently, Wallace et al. (1989) reported that a maximum outdoor air concentration of ethylbenzene of 7.4 μg/m^3 was detected in 9 outdoor samples collected at each of 3 houses while maximum indoor air concentrations at these same residences ranged from 5 to 110 μg/m^3. Mean personal exposures averaged 28 μg/ m^3 (range 4.6-144 μg/ m^3) and the personal/outdoor ratio for ethylbenzene was 16.

The poor quality of indoor air has been linked to a number of symptoms (headache; nausea; irritation of the eyes, mucous membranes, and respiratory system; drowsiness; fatigue; and general malaise) which has been defined as "sick building" syndrome. Most recently, Kostiainen (1994) identified over 200 VOCs in the indoor air of 26 normal houses. Ethylbenzene was detected in 100% of the houses studied at an average concentration of 3.2 μg/m^3 (median 2.41 μg/m^3, minimum 0.62 μg/ m^3, and maximum 10.54 μg/ m^3 concentration). The median concentration of ethylbenzene (2.41 μg/ m^3) in these normal houses was lower in all but one case than ethylbenzene concentrations detected in houses with "sick building" syndrome where the concentrations ranged from 2.25 to 747.24 μg/m^3.

A nationwide study of indoor air concentration of 26 VOCs was conducted in Canada in 1991 (Fellin and Otson 1994). These authors reported that mean indoor ethylbenzene concentrations were 6.46 μg/m^3 (winter), 8.15 μg/m^3 (spring), 4.35 μg/m^3 (summer), and 13.98 μg/m^3 (fall) and that the concentrations declined with an increase in ambient air temperature. At ≤0, 0-15, and ≥15°C, the mean ethylbenzene concentration was 12.76, 7.78, and 6.46 μ/m^3, respectively. These authors concluded that indoor sources of ethylbenzene (primarily from household products) are likely to have a more significant influence on indoor air concentrations than climatic variables.

Concentrations of ethylbenzene were measured in soil gas, and indoor and outdoor air of a home located near a landfill in California (Hodgson et al. 1992). During the first sampling in September, ethylbenzene concentrations were not detected in soil gas or outdoor air, but were detected at 0.6 ppb in basement air. In October, ethylbenzene concentrations averaged 3.3 ppb in soil gas, 0.8 ppb in basement air, and 0.7 ppb in bedroom air. In this study, the authors found that the existence of soil gas contamination alone is not sufficient to result in significantly elevated indoor exposures. The entry rate of ethylbenzene and VOCs form the soil into the house was low. The limited entry that occurred at the conditions of the study was apparently the result of diffusive and advective flux of VOC through the cement blocks used in the

basement wall construction. The authors suggest that there is a general need to identify variables associated with residential sites with the highest potential for significantly elevated indoor exposures resulting from soil gas contamination.

Indoor VOC concentrations were analyzed in 12 California office buildings as part of the California Healthy Building Study (Daisey et al. 1994). These authors reported that ethylbenzene was detected at a geometric mean of 0.5 μg/m^3 (range 0.27-0.98 μg/m^3). These authors also reported that an estimated 82% of indoor air concentrations were contributed from motor vehicle emissions. Hodgson et al. (199 1) reported that concentrations of ethylbenzene in indoor air of a new office building ranged from 7 to 18.7 μg/m^3 over the course of a 14 month sampling period. Furthermore, ethylbenzene indoor air concentrations were higher than those in outdoor air and that the dominant source of VOCs in the building was liquid-process photocopiers and plotters which emitted a characteristic mixture of C_{10},-C_{11} isoparaffmic hydrocarbons.

Wadden et al. (1995) reported average VOC concentrations for indoor air monitored in a sheetfed offset printing shop. These authors reported mean ethylbenzene concentrations ranging from 0.27 to 0.84 mg/m^3 based on 12 1-hour samples.

Levels of ethylbenzene monitored in ambient air show great variation (Jonsson et al. 1985). Generally, air concentrations are much lower in rural areas than in urban areas, where vehicle emissions are thought to be a major contributor of ethylbenzene to ambient air. Ethylbenzene concentrations range from below detection limits in rural areas to 23.1 ppb on busy urban streets (Jonsson et al. 1985). Kelly et al. (1994) reported a median concentration of ethylbenzene of 1.1 μg/m3 (0.25 ppb) for 8,723 samples collected from 93 locations throughout the United States.

An update of the 1980 National Ambient VOCs database prepared for the EPA summarized concentrations of ethylbenzene by site type (Shah and Heyerdahl 1988). Median values are reported because they are less biased by a few high or low concentrations and thus may better represent the data than would average values. Median concentrations for 6 remote and 122 rural locations are reported as 0.156 and 0.013 ppb, respectively. Higher median concentrations were reported for 886 suburban (0.62 ppb) and 1,532 urban (0.62 ppb) locations. The daily median concentration of ethylbenzene considering all site types (including

source dominated [median 0.85 ppb] and workplace air [median 0.28 ppb]) was 0.60 ppb. Table 5-2 lists some monitoring results reported for ethylbenzene in various cities.

Ethylbenzene concentrations at four locations along U.S. Highway 70 near Raleigh, North Carolina, during the month of May were reported to range from 10 to 16 ppb (corrected to include upwind concentrations) (Zweidinger et al. 1988).

Concentrations of ethylbenzene were measured in two tunnels; the Fort McHenry Tunnel in Baltimore, Maryland (June 18-24, 1992) and the Tuscarora Mountain Tunnel in Pennsylvania (September 2-8, 1992) (Zielinska et al. 1996). These authors reported minimum and maximum concentrations for the Fort McHenry Tunnel of 6.3 and 89.2 ppb (on a carbon basis) for bore #3, respectively, and 0.5 and 114.1 ppb (on a carbon basis) for bore #4, respectively, and concentrations for the Tuscarora Tunnel of 1.2 and 11.1 ppb (on a carbon basis), respectively. The total number of light-duty vehicles (LDV) and heavy-duty vehicles (HDV) that passed through each tunnel was 12,273 LDV and 187 HDV for bore #3 and 11,788 LDV and 2,417 HDV for bore #4 of the Fort McHenry Tunnel and 4,887 LDV and 1,041 HDV for the Tuscarora Tunnel.

Ethylbenzene and other VOCs have been found to be removed from waste water in municipal sewers and were emitted to the ambient atmosphere prior to entering a downstream waste water treatment facility in Toronto, Ontario (Quigley and Corsi 1995). These authors measured concentrations of ethylbenzene during 4 monitoring events and found that concentrations ranged from not detectable to 5 ppm. Headspace concentrations of ethylbenzene exhibited a significant weekday/weekend trend. Significant emissions of all VOCs monitored occurred during three of the four monitoring events. Ethylbenzene had the second highest emissions during all periods and ranged from 7 to 14 g/hour (62-130 kg/year) for event 1 and from 1 to 13 g/hour (9-115 kg/year) for event 2. Ethylbenzene emissions at 5 municipal treatment facilities ranged from 0.08 to 93 g/day (0.003-3.9 g/hour). Results of this study suggest that sewers that accept VOC-laden waste water, and that are characterized by significant ventilation and drop structures, can be significant sources of VOC emissions (including ethylbenzene) relative to municipal waste water treatment facilities.

Assmuth and Kalevi (1992) reported that ethylbenzene was detected in municipal solid waste landfill gas at minimum and maximum concentrations ranging from 6.6 to 7.6 mg/m^3, <0.1 to 9.6 mg/m^3, 0.2 to 1.2 mg/m^3, and 85 to 98 mg/m^3 at 4 different landfill sites in Finland. Concentrations of ethylbenzene

Table 5-2. Ethylbenzene Concentrations in Ambient Air Samples Collected in the United States

Location	Concentration	Comments	Reference
Downey, CA	4.6±3.7 ppb (mean±S.D.) 16.1 ppb[a]	February 18–27, 1984; n=100	Singh et al. 1985
Los Angeles, CA	3–12 ppb (range)	September 29–November 13, 1981	Grosjean and Fung 1984
Riverside, CA	1.3±0.8 ppb (mean±S.D.) 4.0 ppb[a]	July 1–13, 1980; n=100	Singh et al. 1985
Denver, CO	2.2±3.1 ppb (mean±S.D.) 18.5 ppb[a]	June 15–28, 1980; n=100	Singh et al. 1985
Chicago, IL	0.8±1.2 ppb (mean±S.D.) 9.5 ppb[a]	April 20–May 2, 1981; n=100	Singh et al. 1985
St. Louis, MI	0.6±0.5 ppb (mean±S.D.) 2.1 ppb[a]	May 29–June 9, 1980 n=100	Singh et al. 1985
Camden, NJ	0.17 ppb (mean)	July 6–August 16, 1981; n=35	Harkov et al. 1983
Elizabeth, NJ	0.26 ppb (mean)	July 6–August 16, 1981; n=37	Harkov et al. 1983
Newark, NJ	0.33 ppb (mean)	July 6–August 16, 1981; n=38	Harkov et al. 1983
Staten Island, NY	1.7±2.5 ppb (mean±S.D.) 17.2 ppb[a]	March 26–April 5, 1981; n=100	Singh et al. 1985
Staten Island, NY	2.7±4.2 ppb (mean±S.D.) 16.7 ppb[a]	April 25–May 1, 1984; n=100	Singh et al. 1985
Philadelphia, PA	0.8±0.8 ppb (mean±S.D.) 7.3 ppb[a]	April 4–22, 1983 n=100	Singh et al. 1985
Pittsburgh, PA	0.8±1.6 ppb (mean±S.D.) 10.5 ppb[a]	April 7–17, 1981; n=100	Singh et al. 1985
Houston, TX	1.5±1.6 ppb (mean±S.D.) 8.2 ppb[a]	March 8–17, 1984; n=100	Singh et al. 1985
Jones State Forest, TX	2.8 ppb[b]	January 4–6, 1978	Seila 1979

[a]Maximum measured concentration
[b]Median concentration in 10 bag samples (median concentration in 5 can samples was 1.0 ppb)

n = number of samples; S.D. = standard deviation

measured in a biogas collection system at the Miron Quarry Municipal Waste Landfill Site in Montreal, Quebec ranged from 2 to 36 mg/m^3 (Goldberg et al. 1995).

Ethylbenzene has been detected in air and soil gas samples collected at 87 and 44 of the 720 NPL hazardous waste sites respectively, where it has been detected in some environmental media (HazDat 1998).

5.4.2 Water

The median ethylbenzene concentration in ambient surface waters in the United States in 1980-82 was less than 5.0 μg/L (ppb) according to EPA's STORET water quality database (Staples et al. 1985). The chemical was detected in 10% of the 1,101 samples collected during that period. Ethylbenzene was also detected in 7.4% of the 1,368 industrial effluent samples collected during 1980-82 at a median concentration of less than 3.0 μg/L (ppb).

From 1989 to 1993, New York City municipal wastewaters were analyzed to determine the frequency of detection of organic priority pollutants, including ethylbenzene (Stubin et al. 1996). Ethylbenzene was detected in 14 of 84 (17%) influent samples at concentrations ranging from 1 to 11 μg/L (ppb) and in only 1 of 84 (1%) effluent samples at a concentration of 2 μg/L (ppb).

Ethylbenzene and other VOCs have been detected in waste water in municipal sewers prior to entering a downstream waste water treatment facility in Toronto, Ontario (Quigley and Corsi 1995). These authors measured concentrations of ethylbenzene in waste water during several monitoring events and found that concentrations ranged from 0.059 to 0.086 mg/L (ppm) in one event and from 7 to 11 mg/L (ppm) in another event. The authors also determined that the stripping efficiency across two drop structures with waste water fall heights of 1 A-3 meters within the sewer system removed 3 l-36% of the ethylbenzene in the waste water. Results of this study suggest that sewers that accept VOC-laden waste water, and that are characterized by significant ventilation and drop structures, can be significant sources of VOC emissions (including ethylbenzene) relative to municipal waste water treatment facilities.

As part of EPA's Nationwide Urban Runoff Program, ethylbenzene was measured in 4% of the municipal runoff samples collected in 15 cities throughout the United States (Cole et al. 1984). The measured ethylbenzene concentration range was 1-2 μg/L (ppb).

Ethylbenzene was measured in seawater at an average concentration of 0.011 μg/L (ppb) and a concentration range of 0.0018-0.022 μg/L (ppb) over a 15month observation period at Vineyard Sound, Massachusetts (Gschwend et al. 1982). Ethylbenzene also has been reported in surface waters of the Gulf of Mexico at a concentration range of 0.0004-0.0045 μg/L (ppb) (Sauer et al. 1978).

Ethylbenzene has been detected in a relatively remote location (Mt. Mitchell, North Carolina) in cloud water at a mean concentration of 170 ng/L (range 0-450 ng/L) (Aneja 1993). The average ram concentration of ethylbenzene was 34 ng/L.

From 1989 to 1990 and from 1992 to 1993, ethylbenzene was monitored in wetland-treated leachate water at a municipal solid waste landfill in central Florida (Chen and Zoltek 1995). During the first sampling period, ethylbenzene was detected in surface water samples ranging from 0.06 to 0.09 ppb, and in groundwater samples ranging from 0.06 to 9.75 ppb. During the second sampling period (1992-93), ethylbenezene was not detected in surface water samples, but was detected in groundwater samples at concentrations ranging from below detection limits to 10.55 ppb. Ethylbenzene was detected in a study of three landfills in central Florida (Hallbourg et al. 1992). These authors reported the concentration of ethylbenzene in groundwater ranging from 1.63 to 9.75, <l to 83.8, and <l to 8.6 μg/L at the 3 different landfill sites. The mean concentration of ethylbenzene detected in landfill leachate from these disposal areas was 17.5 μg/L.

Ethylbenzene does not appear to be widespread in groundwater used for public drinking water supplies. Ethylbenzene was measured in all three drinking water plants sampled as part of the New Orleans Area Water Supply Study conducted by EPA in 1974 (EPA 1985b). The reported concentrations were 1.6, 1.8, and 2.3 μg/L (ppb). The 1982 Ground Water Supply Survey conducted by EPA reported ethylbenzene in only 3 out of 466 random samples at a mean concentration of 0.8 μg/L (ppb) and a maximum concentration of 1.1 μg/L (ppb) (Cotruvo 1985). Chemical monitoring in Wisconsin of over 1,174 public groundwater supplies revealed that ethylbenzene was detected in only 3 community wells (Krill and Sonzongni 1986). The concentration of ethylbenzene detected did not exceed the recommended Wisconsin

drinking water health advisory limit of 1,400 μg/L (ppb) in any of the community wells tested. Ethylbenzene was detected in public drinking water in Rhode Island with concentrations ranging from 1 μg/L to 3 μg/L (ppb) (RIDH 1989). Most recently, ethylbenzene was listed as one of the 58 most frequently detected chemical associated with groundwater contamination (Knox and Canter 1994). Ethylbenzene was listed as having a medium priority with respect to its frequency of occurrence.

Although public underground water supplies do not appear to be significantly affected by releases of ethyl-Benzene private residential wells near landfills, waste sites, or gas stations may be at risk. For example, ethylbenzene has been detected in wells downgradient from landfills in Southern Ontario at concentrations ranging from 12 to 74 μg/L (ppb) (Barker 1987). Chemical monitoring in Wisconsin of 617 private groundwater supplies revealed that ethylbenzene was detected in 12 private wells (Krill and Sonzongni 1986). The concentration of ethylbenzene detected exceeded the state's recommended drinking water advisory limit of 1,400 μg/L (ppb) in 9 of the 12 private wells tested.

Borden and Yanoschak (1990) compared ground and surface water quality impacts associated with North Carolina sanitary landfills. These authors found that ethylbenzene was detected at = 25% of the waste water effluents (receiving secondary treatment) and only 3% of the groundwater sampled in the vicinity of sanitary landfill sites. Groundwater monitoring at 479 hazardous waste disposal sites revealed that ethylbenzene, like the other 9 VOCs monitored, was detected at more than 100 of the 479 sites tested (Plumb 1991). Ethylbenzene was also one of the VOCs detected in groundwater samples from hazardous waste sites in all 10 EPA regions. Rosenfeld and Plumb (1991) reported that ethylbenzene was detected in groundwater at 19% of wood-treatment industry sites based on its frequency of detection and average concentration. Groundwater near an underground coal gasification site in northeastern Wyoming contained concentrations of ethylbenzene ranging from 92 to 400 μg/L (ppb) (Stuermer et al. 1982). Groundwater samples near a fuel spill in the Great Ouse Basin in Great Britain contained ethylbenzene concentrations as high as 1,110 μg/L (ppb) (Tester and Harker 1981).

Ethylbenzene has been detected in surface water, groundwater, and leachate samples collected at 115,488, and 92 of the 720 NPL hazardous waste sites respectively, where it has been detected in some environmental media (HazDat 1998).

5.4.3 Sediment and Soil

The median ethylbenzene concentration (dry weight) detected in sediment in the United States in 1980-82 was 5 μg/kg (ppb) according to EPA's STORET water quality database (Staples et al. 1985). The compound was detected in 11% of 350 sediment samples analyzed. No other recent quantitative information on ethylbenzene concentrations in soil or sediment were found. Ethylbenzene has been detected in soil and sediment samples collected at 379 and 132 of the 720 NPL hazardous waste sites respectively, where it has been detected in some environmental media (HazDat 1998).

5.4.4 Other Environmental Media

Ethylbenzene is not included in the FDA Market Basket Surveys, and little information on concentrations of the compound in foodstuffs is reported in the literature. Trace concentrations of ethylbenzene have been reported in split peas (0.013 mg/kg [ppm]), lentils (0.005 mg/kg [ppm]), and beans (mean concentration 0.005 mg/kg [ppm]; maximum concentration 0.011 mg!kg [ppm]) (Lovegren et al. 1979). Ethylbenzene was reported as one of 227 organic chemicals present in roasted filbert nuts (Kinlin et al. 1972). Most recently, Gorna-Binkul et al. (1996) reported concentrations of ethylbenzene in orange peel (0.0236 μg/g [ppm] dry weight) and in parsley leaves (0.2567 μg/g [ppm] dry weight). The author reported that the differences in concentrations of the VOCs was dependent on the plant species and the morphological part of the plant analyzed. In underground parts (i.e., roots and bulbs) not directly exposed to polluted ambient air during growth, no VOC concentrations were detected. Biedermann et al. (1995) reported concentrations of several VOCs in extra virgin olive oil collected in northwest Italy. These authors found ethylbenzene levels in raw olives of 6 μg/kg (ppb) which increased with time as they were milled to 25 μg/kg (ppb). Levels in the finished olive oils ranged from 11 to 27 μg/kg (ppb) depending on the method used. These authors reported that while some of the ethylbenzene was accumulated in the olives in the orchards, a larger proportions was accumulated as a result of exposure of the oil to air in the milling areas. Ethylbenzene concentrations in olive oil increased from 6 to 235 ppb after 2 days of exposure. The authors concluded that the production process increased the concentration of ethylbenzene in the oil as a result of uptake from the air which was likely to be contaminated with gasoline vapors associated with small vehicles used to move the olives from area to area within the olive oil mill.

Ethylbenzene was also found to migrate from thermoset polyester cooking containers (composed of crosslinking chains of styrene) into belly pork during cooking (Gramshaw and Vandenburg 1995). Migration ranged from <6 to 34 μg/kg for ethylbenzene. The authors also found that the migration measured during the second use of the cookware was generally higher than that during the first use. These authors also reported that ,ethylbenzene concentrations in food cooked in foil-covered dishes was higher than that in the same food cooked uncovered. This was especially true for ethylbenzene that was more volatile than the styrene tested. Ehret-Henry et al. (1994) also reported migration of ethylbenzene from polystyrene containers into dairy products. Concentrations of ethylbenzene ranged from 2 to 4 μg/kg for yogurt and 4 μg/kg for chocolate dessert.

Sack et al. (1992) conducted a survey of VOCs in 1,159 household items, including automotive products, household cleaners and polishes, paint related products, fabric and leather treatments, cleaners for electronic equipment, oils, greases, and lubricants, adhesive-related products, and miscellaneous products. Ethylbenzene was detected in 157 of 658 (24%) of the products tested. The highest mean ethylbenzene concentrations and percentage of products in each category in which ethylbenzene was detected are as follows; 7.2% w/w (wet weight) in 7.5% of automotive products, 2.4% w/w in 47.8% of paint-related products, and 1.0% w/w in 11.8% of fabric and leather treatments.

Hodgson et al. (1996) determined the contribution of environmental tobacco smoke (ETS) to concentrations of VOCs in smoking environments. These authors reported that the average emission factor for ethylbenzene for 6 brands of cigarettes was 101 μg/cigarette (range 83-142 μg/cigarette). The average concentration of ethylbenzene in 5 smoking areas ranged from 1.3 to 8.7 pg!m3 (0.3-2 ppb). Martin et al. (1997) determined the ETS yield of selected analytes, including ethylbenzene, for the 50 top-selling U.S. cigarette brand styles in 1991 and for the University of Kentucky Research cigarette, KlR4F. The ETS was generated by smokers in an environmental test chamber. The ethylbenzene concentrations measured were 8.68 μg/m^3 for full flavor cigarettes, 8.24 μg/m^3 for full flavor low tar cigarettes, and 8.72 μg/m^3 for ultra-low-tar cigarettes. The mean ethylbenzene concentration for all cigarettes was 8.50 pg/m3. The mean ethylbenzene yields by tar category weighted by market share were 8 1.18 μg/cigarette for full flavor cigarettes, 76.79 μg/cigarette for full flavor low tar cigarettes, and 8 1.66 μg/cigarette for ultra low tar cigarettes. The mean ethylbenzene yield for all cigarettes was 79.57 pg/cigarette.

Ethylbenzene was not detected (at a detection limit of 0.025 mg/kg [ppm] wet weight) in any of the 97 biota samples collected from all STORET stations in 1980-83 (Staples et al. 1985). Ethylbenzene was detected at low concentrations (0.0008 mg/g [0.8 ppm]) in oyster tissue, but not in clam tissue from Lake Pontchartrain at Passes, Louisiana (Ferrario et al. 1985). The highest average ethylbenzene concentration of 0.01 mg /kg [ppm] body weight was measured in the tissue of bottomfish from Commencement Bay in Tacoma, Washington (Nicola et al. 1987).

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The highest exposure to ethylbenzene for the general public is most likely to occur via inhalation associated with the use of self-service gasoline pumps or while driving a gasoline-powered motor vehicle especially in high traffic areas or in tunnels (Lawryk et al. 1995). Backer et al. (1997) performed a study that measured exposures associated with the pumping two different blends of fuel under cold conditions in Fairbanks, Alaska. They found that the people in the study had significantly higher levels of gasoline components in their blood after pumping gasoline than before. The changes in VOC levels in blood were similar whether the individuals pumped regular or oxygenated gasoline. Before pumping regular gasoline, the median concentration of ethylbenzene in blood was 0.10 ppb (n=26) with a range of 0.02-0.73 ppb; after pumping, the median concentration was 0.16 ppb with a range of 0.06-l .40 ppb. Before pumping an oxygenated fuel blend that was 10% ethanol, the median concentration of ethylbenzene in blood was 0.11 ppb (n=22) with a range of 0.04-0.55 ppb; after pumping the ethanol blend, the median concentration was 0.16 ppb with a range of 0.06-0.64 ppb.

Lawryk and Weisel(1996) measured in-vehicle concentrations of selected gasoline-derived volatile organic compounds on 113 commutes through suburban New Jersey and 33 New Jersey/New York commutes. In a typical suburban commute, the mean in-vehicle concentration of ethylbenzene was 11.5±18.8 $\mu g/m^3$ (n=52) under low ventilation conditions and 8.5±11.2 $\mu g/m^3$ (n=43) under high ventilation conditions. On the New Jersey turnpike and in the Lincoln Tunnel, the mean in-vehicle concentrations of ethylbenzene were 8.8±10.8 $\mu g/m^3$ (n=32) and 14.3±0.2 $\mu g/m^3$ (n=32), respectively.

Ethylbenzene is ubiquitous in urban and rural atmosphere resulting from vehicular and industrial emissions (Shah and Heyerdahl 1988). Tobacco smoke also provides a general source of exposure to ethylbenzene in indoor air (Wallace et al. 1987c). Wallace et al. (1989) also reported that two activities; painting and the

use of automotive products (carburetor cleaner) led to increased indoor exposure to ethylbenzene by 100-fold. Information on exposure from foods is limited, but is not likely to be a significant source of ethylbenzene for the general population.

One-half of the household drinking water used in the United States is supplied by groundwater, and contamination of groundwater by petroleum products is an increasingly common problem (Beavers et al. 1996). Beavers et al. (1996) conducted a study in a New England household that used groundwater contaminated by gasoline from a leaking underground storage tank. A total daily dose of 379 μg ethylbenzene (204 μg ingested and 175 μg inhaled) was estimated for an exposed subject compared to a median daily dose of 32 μg for unexposed subjects. Of the 17.5 μg inhaled by the exposed subject, 108 μg was attributed to shower activities. The exposed subject and the three non-exposed subjects all were smokers.

The 1982 National Human Adipose Tissue Survey conducted by EPA measured ethylbenzene in 96% of the 46 composite samples analyzed for VOCs (Stanley 1986). A wet tissue concentration range of not detected (detection limit=2 ng/g) to 280 ng/g (ppb) was reported, but an average concentration was not provided.

Ethylbenzene has been detected in breast milk samples collected from 8 of 12 women from various cities in the United States; however, the concentrations were not reported (Pellizzari et al. 1982). The 12 women sampled in the study were residents of Bayonne, New Jersey (6 women), Jersey City, New Jersey (2 women), Bridgeville, Pennsylvania (2 women), and Baton Rouge, Louisiana (2 women).

Ashley et al. (1994) reported blood concentrations of selected VOCs in a reference group of nonoccupationally exposed individuals in the U.S. population. These authors reported a mean ethylbenzene concentration of 0.11 ppb (median 0.06 ppb; 95 percentile value of 0.48 ppb) for 631 individuals. In an earlier study (Ashley et al. 1992), these authors reported a mean ethylbenzene concentration of 0.12 ppb in 13 blood samples. Hajimiragha et al. (1989) conducted a study of 13 non-smokers and 1,4 smokers with no known occupational or hobby-related exposure to volatile organic hydrocarbons. These authors reported a mean and median ethylbenzene concentration of 65 1 ng/L (0.65 1 ppb) and 431 ng/L (0.431 ppb) for the non-smokers and 837 ng/L (0.837 ppb) and 533 ng/L (0.533 ppb) for the smokers. Ethylbenzene concentrations tended to occur at higher concentrations in the blood of smokers than in non-smokers;

however, the difference was not significant. Ashley et al. (1995) also reported that smoking elevated the blood levels of ethylbenzene and was highly correlated with blood levels of 2,5dimethylfuran. These authors reported a mean concentration of 0.10 ng/mL (ppb) (median 0.048 ng/mL; range from below detection limit to 2.7 ng/mL) for non-smokers and a mean concentrations of 0.17 ng/mL (ppb) (median 0.16 ng/mL; range 0.036-0.88 ng/mL) for smokers. To aid in understanding the kinetics of uptake and elimination of volatile organics (including ethylbenzene), Ashley and Prah (1997) measured blood concentrations before, during, and after exposure of five individuals to a mixture of volatile organics in a controlled chamber. The half-lives of the compounds measured were less than 1/2 hour, but the elimination time courses were multiexponential and suggested that, with repeated exposure, bioaccumulation may occur in humans.

Occupational exposure to ethylbenzene in the petroleum industry has been reported in a study that measured ethylbenzene concentrations in air for 49-56 workers during the summer of 1984 (Rappaport et al. 1987). The average air concentrations of ethylbenzene measured over the full work shift for gasoline service station attendants, transport drivers, and outdoor refinery personnel were comparable at 0.063, 0.079, and 0.079 mg/m^3, respectively (14.5, 18.2, and 18.2 ppb, respectively). The authors noted that exposures of service station attendants were significantly lower when vapor recovery systems were present. Personal air monitoring of 35 varnish workers (spraymen) has revealed an average ethylbenzene concentrations of 4.0 ppm, while the average concentration in blood was 61.4 µg/L (Angerer and Wulf 1985). Concentrations of ethylbenzene were monitored in auto paint shops in Spain that used organic solvents (Medinilla and Espigares 1988). These authors reported air concentrations of ethylbenzene ranging from 0.5 to 125.0 mg/m^3 (0.12-28.75 ppm).

The indoor air of screen printing plant workrooms located directly below houses in Amsterdam Holland was found to contain median TWA concentrations of ethylbenzene ranging from <0.03 mg/m^3 (7 ppb) to 1.30 mg/m^3 (299 ppb) and maximum TWA concentrations ranging from 0.11 mg/m^3 (25 ppb) to 3.21 mg/m^3 (739 ppb) (Verhoeff et al. 1988).

Spray-painting and gluing operations can also result in exposure to ethylbenzene; personal air monitoring of workers measured average exposures of approximately 0.5 ppm (2.18 mg/m^3) (Whitehead et al. 1984). Most of the operations measured during the study were performed in ventilation hoods.

5. POTENTIAL FOR HUMAN EXPOSURE

A recent survey of U.S. manufacturers of ethylbenzene conducted by the Styrene and Ethylbenzene Association (SEBA) indicated that typical workplace exposure levels of ethylbenzene in styrene and/or ethylbenzene processing plants were in the range of 0.1-1 ppm for an 8-hour TWA (Helmes 1990). Holz et al. (1995) reported that ethylbenzene air concentrations detected from air sampling in all areas of a styrene production facility located in the former German Democratic Republic ranged from 365 to 2,340 μg/m3 (0.08-0.53 ppm).

According to the National Occupational Exposure Study (NOES) conducted by NIOSH from 1981 to 1983, an estimated 201,838 workers were potentially exposed to ethylbenzene in the workplace (NIOSH 1991). The NOES database does not contain information on the frequency, concentration, or duration of occupational exposure to any of the chemicals listed. The survey provides only estimates of the numbers of workers for whom potential exposure in the workplace is an issue.

The Occupational Safety and Health Administration (OSHA) has set a Permissible Exposure Limit (PEL) based on a TWA of 100 ppm (≈435 mg/m^3) in the workplace (OSHA 1974). The American Conference of Governmental Industrial Hygienists also recommends a Threshold Limit Value (TLV-TWA) of 100 ppm (≈435 mg/m^3) for occupational exposures (ACGIH 1992). The recommended exposure limit (REL) for occupational exposures (TWA) set by the National Institute for Occupational Safety and Health is also 100 ppm (≈435 mg/m^3) for ethylbenzene based on a lo-hour average workday and a 40-hour workweek (NIOSH 1992).

5.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans and briefly considers potential pre-conception exposure to germ cells. Differences from adults in susceptibility to hazardous substances are discussed in Section 2.6, Children's Susceptibility.

Children are not small adults. A child's exposure may differ from an adult's exposure in many ways. Children drink more fluids, eat more food, and breathe more air per kilogram of body weight, and have a larger skin surface in proportion to their body volume. A child's diet often differs from that of adults. The developing human's source of nutrition changes with age: from placental nourishment to breast milk or formula to the diet of older children who eat more of certain types of foods than adults. A child's behavior

and lifestyle also influence exposure. Children crawl on the floor; they put things in their mouths; they may ingest inappropriate things such as dirt or paint chips; they spend more time outdoors. Children also are closer to the ground, and they do not have the judgement of adults in avoiding hazards (NRC 1993).

Children can be exposed to ethylbenzene by inhalation in urban and rural atmospheres contaminated by vehicular and industrial emissions. Tobacco smoke also provides a general source for exposure of children to ethylbenzene in indoor air, especially in the homes where one or both parents smoke. Some household activities, such as painting, can lead to short-term exposures to higher levels of ethylbenzene if ventilation is inadequate. The limited information available on exposure from foods indicates that food is not likely to be a significant source of ethylbenzene for children. Ethylbenzene is heavier than air, and since young children are closer to the ground or floor because of their height, during accidental exposures they may be exposed to more ethylbenzene vapors than adults.

No studies were found that involved body burden measurements on children, and no levels of ethylbenzene or its metabolites were found for amniotic fluid, meconium cord blood or neonatal blood. Ethylbenzene has been detected in breast milk samples collected from 8 of 12 women from various cities in the United States; however, the concentrations were not reported (Pellizzari et al. 1982). The 12 women sampled in the study were residents of Bayonne, New Jersey (6 women), Jersey City, New Jersey (2 women), Bridgeville, Pennsylvania (2 women), and Baton Rouge, Louisiana (2 women). No direct pharmacokinetic experiments have been done to investigate whether significant amounts of ethylbenzene are transferred to breast milk in mammals.

Although no data were found in the literature, it is possible that children playing near hazardous waste sites could be dermally exposed to ethylbenzene in soil or orally exposed by hand-to-mouth activity and/or soil pica. Ethylbenzene, however, is only moderately adsorbed by soil. Since it has a moderately high vapor pressure, it will evaporate fairly rapidly from dry soil. However, under certain soil conditions, ethylbenzene may persist for longer periods of time; it has been detected in soil samples collected at 379 of the 720 NPL hazardous waste sites where it has been detected in some environmental media (HazDat 1998). No information was found concerning dermal and oral bioavailability of ethylbenzene in soil. In the home, intentionally sniffing solvents could lead to high levels of exposure. No information was found concerning differences in the weight-adjusted intakes of ethylbenzene by children.

No exposures of children to ethylbenzene by contamination of workers' homes were found in the Workers' Home Contamination Study conducted under the Worker's Family Protection Act (DHHS 1995).

5.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

In addition to individuals who are occupationally exposed to ethylbenzene (see Section SS), there are several groups within the general population that may receive potentially high exposures (higher than background levels) to ethylbenzene. These populations include individuals living in proximity to sites where ethylbenzene is produced or used in manufacturing or sites where ethylbenzene is disposed, and includes individuals living near the 73 1 NPL hazardous waste sites where ethylbenzene has been detected in some environmental media (HazDat 1998).

Individuals living or working near petroleum refineries or chemical manufacturing plants may receive higher inhalation exposures than those experienced by the general population. Residents living in the vicinity of gasoline stations, high traffic areas, tunnels, parking lots, and highways may also receive a higher than average inhalation exposure since ethylbenzene is a component of gasoline. Ethylbenzene has been detected in air at 87 of the 731 NPL hazardous waste sites where the chemical has been identified in some environmental media. Residential wells downgradient of leaking underground storage tanks, landfills, and hazardous waste sites contaminated with petroleum products and solvents may contain high levels of ethylbenzene. If these residential wells are the primary source of drinking water, this may pose a risk to human health via consumption of contaminated water as well as increased inhalation of and dermal contact with ethylbenzene during showering and bathing. A recent study of indoor air in a home using gasoline-contaminated drinking water found that exposures to ethylbenzene could occur via inhalation during showering and other household activities (Beavers et al. 1996). Ethylbenzene concentrations in shower air were often one to two orders of magnitude higher than non-shower air. These authors reported a total daily household dose of ethylbenzene of 379 μg, with 204 μg derived from ingestion of drinking water and 175 yg derived from inhalation (108 μg from shower-related inhalation and 67 μg from non-shower-related inhalation) to the exposed subject living in the home. The daily dose of ethylbenzene for an unexposed smoker by comparison was estimated to be 32 μg. Ethylbenzene has been detected in groundwater at 488 of the 731 NPL hazardous waste sites where the chemical has been identified in some environmental media.

5.8 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of ethylbenzene is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of ethylbenzene.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.8.1 Identification of Data Needs

Physical and Chemical Properties. The physical and chemical properties of ethylbenzene are well characterized (see Table 3-2) and allow prediction of the transport and transformation of the compound in the environment (Amoore and Hautala 1983; Bohon and Claussen 1951; Chiou et al. 1983; Hansch and Leo 1979; Hodson and Williams 1988; Mabey et al. 1982; Mackay and Shiu 1981; Polak and Lu 1973; Sutton and Calder 1975; Verschueren 1983). No additional studies are needed at the present time.

Production, Import/Export, Use, Release, and Disposal. Ethylbenzene has numerous uses (ACGIH 1986; Merck 1983; Ransley 1984; Verschueren 1983), and production of the chemical has steadily increased since 1983 (C&EN 1994a). Releases occur from a variety of common sources including manufacturing and production (TR196 1998), fuels, automobile exhaust, and fumes from paints, varnishes, solvents, carpet glue, and hot asphalt (Fishbein 1985; Hampton et al. 1983; Junk and Ford 1980; Katzman and Libby 1975; Kitto et al. 1997; Mayrsohn et al. 1978 as cited in NAS 1980; Mukund et al. 1996; NAS 1980; Wallace et al. 1987b). Ethylbenzene also is released from waste waters to the atmosphere in municipal sewer systems (Quigley and Corsi 1995). Therefore, the potential for human exposure to ethylbenezene is considerable. The medium most likely to be contaminated is air, although ethylbenzene has also

been detected in trace amounts in water supplies. Some ethylbenzene-containing wastes are designated as hazardous and are subject to EPA handling and recordkeeping requirements. Information regarding disposal practices would be useful in determining potential sources and levels of exposure to ethylbenzene.

According to the Emergency Planning and Community Right-to-Know Act of 1986,42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. The TRI, which contains this information for 1994, became available in May of 1996. This database will be updated yearly and should provide a list of industrial production facilities and emissions.

Environmental Fate. Ethylbenzene is primarily partitioned to and transported in air (Dewulf and van Langenhove 1997; Eisenreich et al. 1981; Mackay 1979; Masten et al. 1994). The partitioning and transport processes in water, soil, and aquatic life are also well characterized (ASTER 1995; Dewulf et al. 1996; EPA 1980; Kawamura and Kaplan 1983; Ligocki et al. 1985; Swann et al. 1983). Transformation and degradation processes have also been well studied in air (Atkinson and Carter 1984; Atkinson et al. 1978; Grovenstein and Mosher 1970; Herron and Huie 1973; Hoshino et al. 1978; O'Brien et al. 1975; Ohta and Ohyama 1985; Ravishankara et al. 1978; Yanagihara et al. 1977), water (Acton and Barker 1992; Anid et al. 1993; Bouwer and McCarty 1984; Burback and Perry 1993; Ehrhardt and Petrick 1984; Gschwend et al. 1982; Hutchins 1991; Masten et al. 1994; Wakeham et al. 1983; Wilson et al. 1986), and in soil and sediment (Bestetto and Galli 1984 as cited in ECETOC 1986; Chen and Taylor 1995; Hutchins 1991; Hutchins et al. 1991; Jamison et al. 1970; Ramanand et al. 1995; Van der Linden and Thijsse 1965; Yadav and Reddy 1993; Zappi et al. 1996). Additional information on the kinetics of degradation, especially in the vicinity of hazardous waste sites, would be helpful in assessing the risk of exposure to individuals living or working near areas where ethylbenzene might persist in the soil.

Bioavailability from Environmental Media. Ethylbenzene is absorbed following inhalation, oral, and dermal exposures. Information is available on its absorption from air and water, but more data are needed on its oral and dermal bioavailability and absorption from soil and food. Under certain soil conditions, the chemical may persist for longer periods of time. Based on the moderate affinity of ethylbenzene for soil, especially soils with relatively high organic carbon content, individuals who work with or children who play in ethylbenzene-contaminated soil may be at risk of exposure via dermal contact or via consumption of contaminated soil from their unwashed hands. Because of the low bioconcentration factor (BCF) values calculated for ethylbenzene, food would not be expected to be significant sources of ethyl-

benzene exposure. More information on the conditions under which high concentrations of ethylbenzene may persist in soil long enough to become bioavailable through dermal contact with soil, ingestion of soil from unwashed hands, or from contaminated plant material would be useful in fully evaluating the risk posed by this compound at hazardous waste sites.

Food Chain Bioaccumulation. The available data indicate that ethylbenzene does not significantly bioaccumulate in aquatic or terrestrial food chains (BCF value = 167) (ASTER 1995; EPA 1989b; Nunes and Benville 1979) and is therefore unlikely to result in human exposure via ingestion of contaminated foods. However, little information on food residues in commercially important fish and shellfish species is currently available. Additional data on bioaccumulation would be helpful for several commercially important fish and shellfish species.

Exposure Levels in Environmental Media. An extensive amount of atmospheric monitoring data exists and much of it is current (Goldberg et al. 1995; Kostiainen 1994; Mukerjee et al. 1997; Quigley and Corsi 1995; Shah and Heyerdahl 1988; Wallace et al. 1987a, 1987c; Zielinska et al. 1996; Zweidinger et al. 1988). Ethylbenzene has also been detected in surface and groundwater (Barker 1987; Borden and Yanoschak 1990; Chen and Zoltek 1995; Cole et al. 1984; Cotruvo 1985; EPA 1985b; Gschwend et al. 1982; Krill and Sonzogni 1986; Quigley and Corsi 1995; Sauer et al. 1982; Staples et al. 1985; Stubin et al. 1996; Stuermer et al. 1982; Tester and Harker 1981), sediment (Staples et al. 1985), a limited number of foodstuffs (Ferrario et al. 1985; Gorna-Binkul et al. 1996; Kinlin et al. 1972; Lovegren et al. 1979; Nicola et al. 1987); and in cigarette smoke (Hodgson et al. 1996; Martin et al. 1997; Wallace 1986; Wallace et al. 1987c). Most of these data have been collected within the last 10 years. Additional data on the human intake of ethylbenzene from various contaminated environmental media would be helpful. More information on human intake from contaminated water (via dermal, inhalation, or oral exposures), foodstuffs, and soil or sediment (via oral and dermal exposures) would be useful in assessing the risk associated with these possible sources for individuals living near hazardous waste sites.

Reliable monitoring data for the levels of ethylbenzene in contaminated media at hazardous waste sites are needed so that the information obtained on levels of ethylbenzene in the environment can be used in combination with the known body burdens of ethylbenzene to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

Exposure Levels in Humans. Ethylbenzene and its metabolites have been detected in human blood (Angerer and Wulf 1985), urine (Bardodejova 1970; Dutkiewicz and Tyras 1967; Engstrom and Bjurstrom 1978; Gromiec and Piotrowski 1984; Kiese and Lenk 1974; Sullivan et al. 1976; Yamasaki 1984), breast milk (Pellizzari et al. 1982), and adipose tissue (Engstrom and Bjurstrom 1978; Stanley 1986). Most of the monitoring data have come from occupational studies of specific worker populations exposed by inhalation. Members of the general population can be exposed to ethylbenzene through inhalation of fumes while pumping gas or riding in gasoline-powered vehicles (Backer et al. 1997; Lawryk and Weisel 1996; Lawryk et al. 1995). More information of general population exposure to ethylbenzene would be useful. Little information is available on the dietary intake of this chemical. Exposures from this route are likely to be low, except for the consumption of contaminated drinking water by populations living in the vicinity of hazardous waste sites, leaking underground storage tanks, or municipal landfills. More information on the dietary intake of ethylbenzene would be useful, given the possible importance of this exposure route for these populations.

While some information is available on absorption of ethylbenzene from aqueous solutions via dermal exposure (Dutkiewicz and Tyras 1967; Gromiec and Piotrowski 1984), additional information is needed to determine the bioavailability of ethylbenzene adsorbed to soil or sediment and its ultimate absorption via dermal contact or via ingestion of contaminated soils and sediments.

This information is necessary for assessing the need to conduct health studies on these populations.

Exposures of Children. No specific exposure studies on exposures of children were found. When the data need on soil bioavailability for oral and dermal exposure has been addressed, a better assessment can be made on whether soil pica and playing in dirt is a health risk issue for children. Ethylbenzene has been detected in breast milk samples collected from 8 or 12 women from various cities in the United States; however, the concentrations were not reported (Pellizzari et al. 1982). A study to determine current ethylbenzene residues and their sources in breast milk of members of the general population would be helpful.

Current information on whether children are different in their weight-adjusted intake of ethylbenzene via oral and dermal exposures was not located. A study to determine this information would be useful.

Exposure Registries. No exposure registries for ethylbenzene were located. This compound is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The compound will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to the exposure to this compound.

5.8.2 Ongoing Studies

As part of the Third National Health and Nutrition Evaluation Survey (NHANES III), the Environmental Health Laboratory Sciences Division of the National Center for Environmental Health, Centers for Disease Control and Prevention, will be analyzing human blood samples for ethylbenzene and other volatile organic compounds. These data will give an indication of the frequency of occurrence and background levels of these compounds in the general population.

Information about other ongoing studies was obtained from a search of Federal Research in Progress (FEDRIP 1998). These studies are listed in Table 5-3.

Table 5-3. Ongoing Studies on Environmental Effects of Ethylbenzene

Investigator	Affiliation	Research description
Gibson DT	University of Iowa College of Medicine, Iowa City, IA	Mechanisms of enzymatic oxygen fixation
Lieberman RA	Physical Optics Corp., Torrance, CA	Optical sensing and signal identification for bioremediation process control
Logan BE, Arnold RG	Pennsylvania State University, Department of Civil and Environmental Engineering, University Park, PA	Biodegradation of subsurface pollutants by chlorate-respiring microorganisms
Nanny MA	University of Oklahoma, Department of Civil Engineering and Environmental Science, Norman, OK	Molecular-level characterization of bonding and bioavailability of monoaromatic pollutants associated with
Neidle E	University of Georgia Research Foundation, Athens, GA	Regulation of *Acinetobacter calcoaceticus* benzoate degradation
Smith MKL	Bend Research, Inc., Bend, OR	A membrane-based process for the removal of BTEX from glycol dehydration vents
Spormann AM	Stanford University, Department of Civil Engineering, Stanford, CA	Microbial degradation of aromatic hydrocarbons under anaerobic conditions
Starr RC	Idaho Falls, ID	Field demo oxygen for BTEX
Stuck JW	University of Illinois, Natural Resources and Environmental Sciences, Urbana, IL	Surface chemistry of oxidized and reduced clay minerals
Vroblesky DA	Department of the Interior, U.S. Geological Survey, Water Resources Division	Remediation of JP-4 contamination using hydraulic containment and *in situ* biodegradation at the Defense Fuel Supply Center, Charleston, SC
Weiss MEG	Membrane Technoloy and Research, Menlo Park, CA	Control of glycol dehydrator benzene, toluene, ethylbenzene, and xylene emissions

Source: FEDRIP 1998